

I claim:

1 1. A method of representing a set of images for pattern classification, the
2 method comprising:
3 receiving data points corresponding to the set of images in an input space;
4 generating a neighboring graph indicating whether the data points are
5 neighbors;
6 estimating geodesic distances between the data points based upon the
7 neighboring graph;
8 representing each of the data points by an associated feature vector
9 corresponding to the geodesic distances to other data points;
10 applying Fisher Linear Discriminant to the feature vectors associated with
11 the data points to obtain an optimal direction for projecting the
12 feature vectors for pattern classification.

1 2. The method of claim 1, wherein generating a neighboring graph
2 comprises:
3 determining distances between the data points;
4 determining whether the data points are neighbors based on the
5 determined distances;

6 responsive to determining that the data points are neighbors, selecting the
7 determined distance for the neighboring graph;
8 responsive to determining that the data points are not neighbors, selecting
9 an infinite value for the neighboring graph.

1 3. The method of claim 2, wherein determining whether the data points are
2 neighbors comprises selecting a predetermined number of closest data points from each
3 data point based on the determined distance as the neighbors.

1 4. The method of claim 2, wherein determining whether the data points are
2 neighbors comprises selecting data points within a predetermined radius from each data
3 point based on the determined distance as the neighbors.

1 5. The method of claim 1, wherein estimating the geodesic distance between
2 the data points comprises approximating the geodesic distance between the data points
3 with a distance covered by a sequence of short hops between neighboring data points on
4 the neighboring graph using the Floyd-Warshall algorithm.

1 6. The method of claim 1, wherein applying Fisher Linear Discriminant to
2 the feature vectors comprises projecting the feature vectors to a lower dimensional space
3 lower in dimension than the input space so as to substantially maximize a variance
4 between clusters of feature vectors while substantially minimizing the variance within
5 each cluster of the feature vectors.

1 7. The method of claim 6, wherein the variance between the clusters of the
2 feature vectors is represented by a between-class scatter matrix and the variance within
3 each cluster of the feature vectors is represented by a within-class scatter matrix.

1 8. The method of claim 7, wherein the feature vectors are projected to the
2 lower dimensional space so as to substantially maximize a ratio of the between-class
3 scatter matrix to the within-class scatter matrix.

1 9. The method of claim 1, wherein the images are face images or digit
2 images.

1 10. A method of representing a set of images for pattern classification, the
2 method comprising:

3 receiving data points corresponding to the set of images in an input space;
4 generating a neighboring graph indicating whether the data points are
5 neighbors;

6 estimating geodesic distances between the data points based upon the
7 neighboring graph;

8 representing each of the data points by an associated feature vector
9 corresponding to the geodesic distances to other data points;

10 applying Kernel Fisher Linear Discriminant to the feature vectors
11 associated with the data points to obtain an optimal direction for
12 projecting the feature vectors for pattern classification.

1 11. The method of claim 10, wherein generating a neighboring graph
2 comprises:
3 determining distances between the data points;
4 determining whether the data points are neighbors based on the
5 determined distances;
6 responsive to determining that the data points are neighbors, selecting the
7 determined distance for the neighboring graph;
8 responsive to determining that the data points are not neighbors, selecting
9 an infinite value for the neighboring graph.

1 12. The method of claim 11, wherein determining whether the data points are
2 neighbors comprises selecting a predetermined number of closest data points from each
3 data point based on the determined distance as the neighbors.

1 13. The method of claim 11, wherein determining whether the data points are
2 neighbors comprises selecting data points within a predetermined radius from each data
3 point based on the determined distance as the neighbors.

1 14. The method of claim 10, wherein estimating the geodesic distance
2 between the data points comprises approximating the geodesic distance between the data
3 points with a distance covered by a sequence of short hops between neighboring data
4 points on the neighboring graph using the Floyd-Warshall algorithm.

1 15. The method of claim 10, wherein applying Kernel Fisher Linear
2 Discriminant to the feature vectors comprises:

3 projecting the feature vectors to a high dimensional feature space using a
4 projection function;
5 generating Kernel Fisherfaces for the feature vectors projected to the high
6 dimensional feature space;
7 projecting the feature vectors to a lower dimensional space lower in
8 dimension than the input space and the high dimensional feature
9 space based on the Kernel Fisherfaces so as to substantially
10 maximize a variance between clusters of feature vectors while
11 substantially minimizing the variance within each cluster of the
12 feature vectors.

1 16. The method of claim 15, wherein the variance between the clusters of the
2 feature vectors is represented by a between-class scatter matrix and the variance within
3 each cluster of the feature vectors is represented by a within-class scatter matrix.

1 17. The method of claim 16, wherein the feature vectors are projected to the
2 lower dimensional space so as to substantially maximize a ratio of the between-class
3 scatter matrix to the within-class scatter matrix.

1 18. The method of claim 17, wherein a fraction of an identity matrix is added
2 to the within-class scatter matrix.

1 19. The method of claim 15, wherein the projection function $\Phi(x)$ satisfies
2 the following relation:

$$k(x, y) = \Phi(x) \bullet \Phi(y)$$

4 where $k(x,y)$ is a kernel function, $\Phi(x) \bullet \Phi(y)$ is the dot product of the projection
5 functions $\Phi(x)$ and $\Phi(y)$, and x and y are real number variables.

1 20. The method of claim 10, wherein the images are face images or digit
2 images.

1 21. A system for representing a set of images for pattern classification, the
2 system comprising:

3 neighboring graph generation module for receiving data points
4 corresponding to the set of images in an input space and for
5 generating a neighboring graph indicating whether the data points
6 are neighbors;
7 a geodesic distance estimation module for estimating geodesic distances
8 between the data points based upon the neighboring graph;
9 a Fisher Linear Discriminant module for representing each of the data
10 points by an associated feature vector corresponding to the
11 geodesic distances to other data points and for applying Fisher
12 Linear Discriminant to the feature vectors associated with the data
13 points to obtain an optimal direction for projecting the feature
14 vectors for pattern classification.

1 22. The system of claim 21, wherein the neighboring graph generation module
2 generates the neighboring graph by:
3 determining distances between the data points;

4 determining whether the data points are neighbors based on the
5 determined distances;
6 responsive to determining that the data points are neighbors, selecting the
7 determined distance for the neighboring graph;
8 responsive to determining that the data points are not neighbors, selecting
9 an infinite value for the neighboring graph.

1 23. The system of claim 22, wherein determining whether the data points are
2 neighbors comprises selecting a predetermined number of closest data points from each
3 data point based on the determined distance as the neighbors.

1 24. The system of claim 22, wherein determining whether the data points are
2 neighbors comprises selecting data points within a predetermined radius from each data
3 point based on the determined distance as the neighbors.

1 25. The system of claim 21, wherein the geodesic distance estimation module
2 estimates the geodesic distance between the data points by approximating the geodesic
3 distance between the data points with a distance covered by a sequence of short hops
4 between neighboring data points on the neighboring graph using the Floyd-Warshall
5 algorithm.

1 26. The system of claim 21, wherein the Fisher Linear Discriminant module
2 applies Fisher Linear Discriminant to the feature vectors by projecting the feature vectors
3 to a lower dimensional space lower in dimension than the input space so as to
4 substantially maximize a variance between clusters of feature vectors while substantially
5 minimizing the variance within each cluster of the feature vectors.

1 27. The system of claim 26, wherein the variance between the clusters of the
2 feature vectors is represented by a between-class scatter matrix and the variance within
3 each cluster of the feature vectors is represented by a within-class scatter matrix.

1 28. The system of claim 27, wherein the feature vectors are projected to the
2 lower dimensional space so as to substantially maximize a ratio of the between-class
3 scatter matrix to the within-class scatter matrix.

1 29. The system of claim 21, wherein the images are face images or digit
2 images.

1 30. A system for representing a set of images for pattern classification, the
2 system comprising:

3 neighboring graph generation module for receiving data points
4 corresponding to the set of images in an input space and for
5 generating a neighboring graph indicating whether the data points
6 are neighbors;
7 a geodesic distance estimation module for estimating geodesic distances
8 between the data points based upon the neighboring graph;
9 a Kernel Fisher Linear Discriminant module for representing each of the
10 data points by an associated feature vector corresponding to the
11 geodesic distances to other data points and for applying Kernel
12 Fisher Linear Discriminant to the feature vectors associated with

the data points to obtain an optimal direction for projecting the feature vectors for pattern classification.

1 31. The system of claim 30, wherein the neighboring graph generation module
2 generates the neighboring graph by:

3 determining distances between the data points;

determining whether the data points are neighbors based on the

responsive to determining that the data points are neighbors, selecting the

⁷ determined distance for the neighboring graph;

8 responsive to determining that the data points are not neighbors, selecting

⁹ an infinite value for the neighboring graph.

I 32. The system of claim 31, wherein determining whether the data points are
neighbors comprises selecting a predetermined number of closest data points from each
data point based on the determined distance as the neighbors.
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1 33. The system of claim 31, wherein determining whether the data points are
2 neighbors comprises selecting data points within a predetermined radius from each data
3 point based on the determined distance as the neighbors.

1 34. The system of claim 30, wherein the geodesic distance estimation module
2 estimates the geodesic distance between the data points by approximating the geodesic

3 distance between the data points with a distance covered by a sequence of short hops
4 between neighboring data points on the neighboring graph using the Floyd-Warshall
5 algorithm.

1 35. The system of claim 30, wherein the Kernel Fisher Linear Discriminant
2 module applies Kernel Fisher Linear Discriminant to the feature vectors by:
3 projecting the feature vectors to a high dimensional feature space using a
4 projection function;
5 generating Kernel Fisherfaces or the feature vectors projected to the high
6 dimensional feature space;
7 projecting the feature vectors to a lower dimensional space lower in
8 dimension than the input space and the high dimensional feature
9 space based on the Kernel Fisherfaces so as to substantially
10 maximize a variance between clusters of feature vectors while
11 substantially minimizing the variance within each cluster of the
12 feature vectors.

1 36. The system of claim 35, wherein the variance between the clusters of the
2 feature vectors is represented by a between-class scatter matrix and the variance within
3 each cluster of the feature vectors is represented by a within-class scatter matrix.

1 37. The system of claim 36, wherein the feature vectors are projected to the
2 lower dimensional space so as to substantially maximize a ratio of the between-class
3 scatter matrix to the within-class scatter matrix.

1 38. The system of claim 30, wherein the images are face images or digit
2 images.

1 39. The system of claim 35, wherein the projection function $\Phi(x)$ satisfies the
2 following relation:

$$k(x, y) = \Phi(x) \bullet \Phi(y)$$

- 4 where $k(x, y)$ is a kernel function, $\Phi(x) \cdot \Phi(y)$ is the dot product of the projection
- 5 functions $\Phi(x)$ and $\Phi(y)$, and x and y are real number variables.

1 40. A computer program product for representing a set of images for pattern
2 classification, the computer program product stored on a computer readable medium and
3 adapted to perform a method comprising:

- 4 receiving data points corresponding to the set of images in an input space;
- 5 generating a neighboring graph indicating whether the data points are
- 6 neighbors;

7 estimating geodesic distances between the data points based upon the
8 neighboring graph;

representing each of the data points by an associated feature vector

10 corresponding to the geodesic distances to other data points;

11 applying Fisher Linear Discriminant to the feature vectors associated with
12 the data points to obtain an optimal direction for projecting the
13 feature vectors for pattern classification.

1 41. A computer program product for representing a set of images for pattern
2 classification, the computer program product stored on a computer readable medium and
3 adapted to perform a method comprising:
4 receiving data points corresponding to the set of images in an input space;
5 generating a neighboring graph indicating whether the data points are
6 neighbors;
7 estimating geodesic distances between the data points based upon the
8 neighboring graph;
9 representing each of the data points by an associated feature vector
10 corresponding to the geodesic distances to other data points;
11 applying Kernel Fisher Linear Discriminant to the feature vectors
12 associated with the data points to obtain an optimal direction for
13 projecting the feature vectors for pattern classification.

1 42. A system for representing a set of images for pattern classification, the
2 system comprising:
3 means for receiving data points corresponding to the set of images in an
4 input space and for generating a neighboring graph indicating
5 whether the data points are neighbors;
6 means for estimating geodesic distances between the data points based
7 upon the neighboring graph;
8 means for representing each of the data points by an associated feature
9 vector corresponding to the geodesic distances to other data points

10 and for applying Fisher Linear Discriminant to the feature vectors
11 associated with the data points to obtain an optimal direction for
12 projecting the feature vectors for pattern classification.

1 43. A system for representing a set of images for pattern classification, the
2 system comprising:

3 means for receiving data points corresponding to the set of images in an
4 input space and for generating a neighboring graph indicating
5 whether the data points are neighbors;

6 means for estimating geodesic distances between the data points based
7 upon the neighboring graph;

8 means for representing each of the data points by an associated feature
9 vector corresponding to the geodesic distances to other data points
10 and for applying Kernel Fisher Linear Discriminant to the feature
11 vectors associated with the data points to obtain an optimal
12 direction for projecting the feature vectors for pattern
13 classification.